HUMAN ADAPTATION TO TEMPERATURE CONDITIONS WITH THE OBJECT OF INCREASING RESISTANCE TO HEAT

P.V. Buyanov, A.V. Beregovkin, and M.A. Migulina

In the course of his work, man often has to withstand the action of high temperatures. During space flight hyperthermic conditions may be created. In addition to protective measures, it is desirable to increase the resistance of the body to high temperatures, and one of the principal ways in which this can be done is by specific training [2, 3, 6, 8].

Because of the importance of the pattern of the astronaut's reactivity to high temperatures, A.A. Dorodnitsyna and co-workers studied methods of increasing resistance to heat by specific training. In the experiments described below, by means of clinical and physiological methods we studied the after-period, and from the stability and magnitude of the results thus obtained we judged the changes taking place in function of the cardiovascular system, external respiration, renal function, the blood system, and the level of adaptation of the subjects examined. The after-period was studied during exposures of 1 h in a chamber at +50 and +60° and of 50 min at a temperature of +70°. Exposure to temperatures of 50 and 60° was carried out daily or on alternate days. Exposure to a temperature of +70° was carried out only on alternate days. The duration of the adaptation cycle ranged from 1 to 2 months. In the background investigation, after every 10 exposures to the high temperature, at the end of the adaptation cycle, and thereafter every 25-30 days for 2-4 months, a temperature test was performed (+80° with the longest possible exposure). The criterion for stopping the experiment was an appreciable worsening of the patient's general and subjective condition, a rise of the pulse rate above 150 beats/min, or a rise of temperature by more than 3° (A.A. Dorodnitsyna and G.V. Kaliberdin). / 311

The objects of the clinical and physiological investigations in the after-period of the adaptation cycle and at the end of this period were to look for the appearance of changes affecting the cardiovascular system, the peripheral blood, external respiration and renal function, to determine the stability of these changes, and to ascertain the significance of the changes found in determining the level of adaptation of the subject. Besides clinical examination by specialists, spirography was performed, the body temperature taken, the gas exchange studied, the blood and urine analyzed, the hematocrit index obtained, and tacho-oscillograms from the arm and arterial oscillograms recorded. By simultaneously recording the tacho- and arterial oscillograms, the fundamental hemodynamic indices could be determined and an estimate made of the work of the heart, the tone of the larger arteries, and the state of the peripheral resistance. The stroke and minute blood volumes were calculated by N.N. Savitskiy's modification of the Bremser—Ranke formula.

To begin with the background data were established. Thereafter investigations were carried out periodically one every 10-15 days in the course of the adaptation cycle. At the end of the cycle the investigations were repeated every 25-30 days until disappearance of the changes which had been found. The investigations were carried out after the temperature test (80°). In most cases the orthostatic test was used. Observations and clinical and physiological tests were carried out on 17 men aged 22-26 years. All were declared healthy and fit to take part in tests involving exposure to high temperatures. /312

RESULTS

First series (table). During the adaptation cycle a gradual fall of arterial pressure was observed (minimal by 11-17 mm Hg, mean dynamic pressure by 10-18 mm, and piezometric or lateral pressure by 9-12 mm Hg). The pulse pressure was slightly increased (to 10 mm Hg). Soon after the end of adaptation the arterial pressure returned to its initial level. The heart rate and cardiac output (the stroke and minute blood volumes) were not significantly changed. The trend of the changes in the precapillary system corresponded to the dynamics of the minute circulation of the blood. The velocity of spread of the pulse wave along the elastic vessels (V_e) was unchanged, while that along the muscular vessels (V_m) fell by 7-27%. The ratio V_e/V_m fell by 12-15% by the end of the adaptation period.

TABLE: Series of Investigations Undertaken

Series of investigations	Temperature in chamb. °C	Frequency of experiments	Number of subjects	Series of investigations	Temperature in chamb. °C	Frequency of experiments	Number of subjects
I	50	on alternate days	4 men	IV	60	daily	3 men
II	50	daily	4 men	V	70	on alternate days	3 men
III	60	on alternate days	3 men				

Note: Duration of experiment 60 min in series I-Iv and 50 min in series V.

Although the gas exchange was investigated under conditions close to those of basal metabolism, the oxygen consumption in the initial state was raised slightly to 267-319 ml/min. In the adaptation period the oxygen utilization of two subjects rose by 13 and 15%. Their CO_2 elimination rose correspondingly.

Their respiratory quotient was essentially unchanged. The pulmonary ventilation rose in the first period and fell by 10-12% in the second period of adaptation in all subjects. At the end of the adaptation cycle the indices of gas exchange and / 313
of pulmonary ventilation returned to their initial level within a day or two. The vital capacity of the lungs and the partial lung volumes were essentially unchanged.

After adaptation for 15-20 days the hematocrit volume began to increase*. A steady increase in the erythrocyte volume was found in two subjects. In the rest the increase in hematocrit index was transitory. The mean erythrocyte volume increased by 15-61%. Starting from the 30th-40th day of adaptation the leukocyte count rose gradually without any appreciable shift in the leukocyte formula.

The first control examination after the temperature test showed increases of 16-21% in the erythrocyte count and of 0.4-1.2 g% in the hemoglobin concentration. The hematocrit index was increased by 5-48% and the mean erythrocyte volume by 4-61%. The leukocyte count was increased on the average by 11%, mainly on account of the neutrophils. After the second temperature test on one subject a shift to the left of the neutrophils as far as the appearance of metamyelocytes was observed. After the temperature test the subjects' diuresis was reduced, albuminuria appeared (up to 0.033% and higher), and hyaline casts were found in the sediment (1-2 per preparation). The changes discovered disappeared during the first day as a rule, and only occasionally were detectable until the 4th day after exposure. Changes in the urine of two subjects diminished considerably in the course of adaptation.

The observed changes resulting from adaptation were unstable and disappeared in the first 10-15 days after the adaptation cycle ended. Some subjects showed poor powers of adaptation to the action of high temperatures. One subject, for example, developed signs of automatic vasomotor instability during exposure to high temperatures and he took no further part in the tests.

Second series. After each exposure the subjects were generally tired and exhausted and complained of headache. The subjective picture was more marked than in the subjects of the first series. With the systematic exposure to high temperatures the arterial pressure fell by 5-12 mm Hg. The heart rate was reduced by 3-15 beats per minute. The observed changes disappeared 10-15 days after the end of the adaptation cycle. During the exposures to a high temperature marked variations were found in the values of the stroke volume of the circulation. By the end of adaptation the indices of cardiac output had returned to their original level. The V_m/V_e ratio was reduced by 5-19% except in one subject, in whom no perceptible change took place. By the end of adaptation the / 314
initial value of V_m/V_e had been restored. During the after-period considerable fluctuations of the stroke and minute blood volumes were observed, mainly rising to 120-162% of their initial values.

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*The hematologic investigations and urine analyses were performed by M.Z. Ginzburg.

The oxygen consumption fell from 305-335 ml/min by 12-23%. The CO_2 elimination was reduced by 40-53%. Consequently, the respiratory quotient fell to 0.75-0.68. The minute volume of ventilation (MVV) was reduced in three subjects by 71-74%, mainly through slowing of the respiration rate and, to a lesser extent, through a change in the respiratory volume. Tests showed that 2 months after the end of the adaptation cycle the MVV had not yet reached its original level.

No appreciable changes were observed in the blood. In one animal only the erythrocyte count was lowered by 13% and the hemoglobin concentration reduced from 14.7 to 13.2 g%.

In the temperature test performed during adaptation a lowering of the arterial pressure was observed, the mean dynamic pressure falling by 4-15 mm Hg, the stroke pressure increasing by 6-20 mm Hg, and the true pulse pressure falling by 5-9 mm Hg. The velocity of spread of the pulse wave was reduced in both elastic and muscular arteries without any appreciable change in the V_m/V_e ratio. Only the orthostatic test caused some decrease in the V_m/V_e ratio instead of its usual increase observed during this test. In two subjects this type of unfavorable reaction of the vascular tone during the orthostatic test was observed throughout the period of observation at the end of the adaptation cycle (3-4 months).

After the temperature test the gas exchange increased. The leukocyte count was raised by 7-58%. A more marked leukocytic response with a shift of the neutrophils to the left and a moderate lymphocytopenia was observed in the second period of the adaptation cycle.

As a rule albumin, hyaline casts, and a few erythrocytes appeared in the urine. Changes in the urine of one subject were more marked and persisted for 3-4 days. After 2-3 weeks the changes in the urine were considerably reduced or had disappeared. During the orthostatic test the main feature was a decrease in stroke volume, with a slight decrease in the minute volume of the circulating blood and a fall in the V_m/V_e ratio.

In this series of experiments the adaptive response to systematic exposure to high temperatures included lowering of the arterial pressure, slowing of the pulse and respiration, a decrease in the cardiac output, and reduction of the gas exchange and the minute volume of pulmonary ventilation. From the dynamics /315
of these indices after the end of adaptation it appears that there is an increase in resistance to heat which is of relatively short duration (under 1 month). Meanwhile, the effect of specific adaptation on the vascular tone continues much longer (3-4 months). Some of the changes in the hemodynamics, gas exchange, peripheral blood and urine were due not only to the influence of temperature on the human body, but also, and more especially, to individual variations which must be taken into account during job placement.

Third series. In the period of systematic exposure to high temperatures again the most characteristic features were lowering of the arterial pressure

and slowing of the pulse. The minute volume of circulating blood showed inconstant changes (from +30 to +38%). The V_m/V_e ratio fell in only one subject. The oxygen consumption rose in 1 (+74%) and fell in 2 subjects by 20 and 32% respectively. The respiration rate became slower. The minute volume of ventilation of the lungs diminished by 21-26%. In one subject the leukocyte count rose in the course of adaptation from 7000-7500 to 9000-9500 cells/mm^3. The number of leukocytes of the neutrophilic series rose by 90% and the number of eosinophils by 3.5 times. Not until 1 month after the end of adaptation to high temperatures did the leukocyte count fall to 8200 cells/mm^3.

The temperature test showed a lowering of the arterial pressure, an increase in the stroke pressure, quickening of the pulse by 11-16 beats/min, and a decrease in the V_m/V_e ratio by 5-18%. The erythrocyte count fell slightly. The hematocrit volume of the erythrocytes increased by 9-13%. The leukocyte count rose by 6-50%. During subsequent tests the leukocytic response was less marked, which is attributable to adaptation. The adaptive changes in the subject with an increased leukocytic response were of short duration, for 1 month after the end of the adaptation cycle, when this test was performed after the temperature test, a marked leukocytic response was observed, with a shift to the left as far as the appearance of metamyelocytes. Traces of albumin, recent erythrocytes, and occasionally hyaline casts appeared in the urine. In two subjects the process of adaptation had no effect on the changes observed in the urine. Adaptation was of short duration and could be discerned for the first 10-20 days.

Fourth series. The same changes were found as in the first three series. The phases in the response of the circulatory system were more clearly defined. In the initial period an increase of 28-44% in the minute volume of the circulation was observed, followed by a decrease of 21-26% in the second period. A reduction in cardiac output coincided with a decrease in gas exchange. The change in vascular tone was more marked. The ratio V_m/V_e at rest was 13-23% below /316 the initial level, and in the orthostatic test a still further decrease was observed. In one subject considerable hypotension was found in the period of systematic exposure to high temperatures. The minimal pressure fell to 44, the mean dynamic pressure up to 65, and the lateral pressure to 85 mm Hg. Bradycardia, which was characteristic of this subject in the initial state, gave way to quickening of the pulse from 44 to 70 beats/min.

This oxygen consumption fell by 16-40% and the CO_2 elimination by 11-29%. The respiration rate fell from 15-16 to 11-13 per minute and the minute volume of ventilation of the lungs was reduced by 14-28%. The decrease in MVV took place gradually, as exposures to a high temperature continued. The vital capacity of the lungs and its constituent partial volumes were unchanged.

It is an interesting fact that in this series of the investigation the hematocrit volume of the erythrocytes was unchanged, while the leukocyte count fell by 22-37%. After the temperature test a leukocytic response was observed. The leukocyte count rose by 7-124%.

In the fifth series only laboratory tests were performed. More marked changes in the blood and urine after the temperature test were observed in the first period of the adaptation cycle. In the second period they were slight or absent.

DISCUSSION

Systematic exposures to high temperatures, used in order to increase resistance to heat, did not noticeably affect the subjects' sense of fitness. In a few cases some decrease in tolerance to high temperatures was observed. These subjects showed autonomic vasomotor and endocrine instability, a marked and persistent hyper- or hypotensive response, and long-lasting leukocytosis. The differences between the subjects revealed by these tests demonstrate the importance of the individual qualities they possess, associated with inadequacy of neuro-endocrine regulation of the circulation in some cases and with differences in hemopoiesis in others. The results obtained must be taken into consideration in cases when medical examination for employment associated with exposure of the human body to high temperatures is involved.

Too little attention has been paid in the literature to the question of adaptation to high temperatures. According to some reports, persons with certain disturbances of function and with certain diseases, such as hyper- or hypofunction of the thyroid, neurological disturbances, disorders of the endocrine glands or of metabolism, and chronic diseases, possess lowered tolerance to high temperatures [12]. Our results are interesting from the standpoint that persons who, when tested after systematic exposure to high temperatures, showed persistent disturbances of function, were declared healthy on the basis of the initial clinical and physiological examination. / 317

We found several consistent changes in the subjects resulting from systematic exposure to high temperatures (between 50 and 70°). A definite hypotensive response was present, with slowing of the pulse, reduction of the gas exchange, a decrease in pulmonary ventilation, and so on. These changes were more regularly found in the second period of the adaptation cycle, in all series of the investigation. In my opinion, the changes discovered are important in adaptation of the body to high temperatures and they reflect the development of adaptation processes in the course of repeated exposure to them. Many investigators who have studied acclimatization in regions with a hot climate have also found, in cases when adaptation was successful, slowing of the pulse, lowering of the arterial pressure, a decrease in the cardiac output, and a reduction in the gas exchange [11, 13, 15]. The cyclic nature of the changes in the hemodynamics and gas exchange revealed by our experiments was found quite distinctly in earlier studies of acclimatization to high temperatures. Z.I. Umidova and A.D. Slonim [11, 13] found an initial increase in the stroke and minute volumes of blood and in the gas exchange. In the second period they observed a decrease in the cardiac output and oxygen utilization.

According to our findings, adaptation to the temperature factor takes place in two stages. In the first period an increase in the activity of the circulatory system and in the gas exchange is observed. In the second stage the circulating

blood volume falls and the oxygen consumption is reduced. In some cases the decrease in gas exchange is greater than the change in the minute volume of circulating blood.

This last observation indicates that the circulation of blood is not sufficiently effective and that adaptation is unstable. A decrease in the oxygen consumption with an adequate or slightly greater decrease in the volume of the cardiac output are evidence of better adaptation to high temperatures.

The lowering of the arterial pressure and simultaneous increase in the hemodynamic stroke are signs of a decrease in vascular tone. The disturbance of vascular tone is confirmed by the decrease in the ratio between the moduli of elasticity at rest and its further decrease during the orthostatic test. These distinctive features of the changes in vascular tone during systematic exposure to high temperatures must be taken into consideration when choosing methods of /318 increasing the resistance of astronauts to heat, for a lowering of vascular tone may significantly affect tolerance to overloads and, possibly, to weightlessness.

The character of the changes in the blood and urine during exposure to the temperature factor has been inadequately studied in the literature. Most investigators have studied conditions of acclimatization in a hot climate and there are few indications of changes in the blood and urine during exposure to heat under special conditions. Many workers found no essential changes in the red blood [2, 9]. F.T. Agarkov and V.N. Belyayeva [2] found cyclic responses of the red blood in their experiments. Other workers found a decrease in the leukocyte count, mainly on account of a neutropenia [1, 4, 16]. A leukocytic response with a shift of the formula to the left was observed in animals kept in a hot chamber. In the course of adaptation the degree of the changes in the white blood cells increased [4, 5]. In dogs, a leukocytic response takes place during exposure to a relatively moderate positive temperature (from +30 to +40°) and leukopenia during exposure to higher temperatures (from +50 to +60°). It is clear from these results that our knowledge of the dynamics of the blood picture during acclimatization is incomplete. We consider that an increase in the leukocyte count is observed in the first period of systematic exposure to the action of high temperatures. Later there is a gradual decrease in the leukocyte count and a reduction in the increase in the leukocyte count taking place during the temperature test. The marked and persistent leukocytic response of the blood and the considerable changes in the urine associated with direct exposure to the temperature factor indicate lowered tolerance and unsatisfactory adaptation to it.

The decisive factor in the choice of method of adaptation is the stability of the adaptation achieved. Our findings, however, justify the conclusion that the adaptation is relatively short in duration. This conclusion is confirmed by data obtained by other investigators [10] and also by the direct results of the temperature tests carried out on our subjects (A.A. Dorodnitsyna, G.V. Kaliberdin and others). Our findings thus confirm the conclusions drawn by other workers, namely, that stability of the adaptation produced by exposure to high temperatures is inadequate. In our subjects signs of adaptation were found for the first 10-30 days, depending on the magnitude of the temperature factor and on its frequency of repetition. The duration of the development of adaptation is evidently about twice as long as duration of its persistence after the exposures to the temperature factor have ceased.

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